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Emily Brumit, Ritta Merza, Katharine McErlean and/or Jennifer Morris
Managers, Notice of Inquiry (NOI) Regarding Electric Vehicles
Illinois Commerce Commission
160 North LaSalle, Suite C-800
Chicago IL 60601

Dear NOI Managers,

Although I speak as a retired private citizen of Illinois, I draw on decades of research on alternative fuels generally and plug-in electric vehicle technology particularly. In my prior professional capacity my colleagues and I worked with the state of Illinois on the topic of addition of ethanol to gasoline. This has been successful, but only over several decades. Electrifying transportation will certainly also take decades and require repeated evaluations and adjustments along the way.

I enclose a discussion of my present professional judgement about the most important immediate decisions regarding plug-in electric vehicle (PEV) success – namely decisions regarding residential charging technology and infrastructure. These generally overlooked choices are fundamental. Rather than address developing policies to *encourage* plug-in vehicle success, I focus on avoiding many present policies that will, perhaps unintentionally, discourage success. I recommend that utilities focus on quality assured, safe low power charging at the residence. From most policy makers' perspective, this would be a shift of emphasis. Where the NOI asks for comments on how best to accomplish sophisticated active control of plug-in vehicles, I offer comments on how best to implement unsophisticated, low security risk, passive control strategies that have the potential to benefit the grid and make use of existing wind generation at very low cost. Plug-in hybrids are ideal for implementation of this strategy. Though it should not at this time be top priority, I do allow that development of higher power charging with active control is also desirable in the long term to increase the capture of both wind and solar energy. Due to power and energy flexibility provided with large battery packs, all-electric and range-extended electric vehicles are ideal for implementation of this strategy.

You will find that these professional judgments address many of the questions in the NOI.

I also take this opportunity to briefly explain a related professional judgment. Based on estimates I have been involved with developing, the "midcontinent" region in which Illinois resides requires a different set of priorities for plug-in vehicle technology than do coastal regions where weather extremes are much less severe and average driving distance per vehicle is less. While the long driving distances of customers in the midcontinent make fast intercity refueling more important, the cold temperature deficiencies regarding fast charging of all-electric vehicles create cold climate marketability problems that former colleagues and I saw in sales data for the BMW i3 model.

Though the NOI does not ask for this judgment to be expressed, my long-term technology development advice to the midcontinent generally, and to Illinois, is to encourage the class of vehicles known as plug-in hybrids, with a stipulation that the liquid fuel to be used by the internal combustion engines in longer range versions of those vehicles have a flex fuel capability to use either a high-octane gasoline or high-level ethanol blend. From the state's perspective, if plug-in vehicles succeed, this would help avoid shut down of ethanol production and sales capability developed over decades.

It would also provide benefits from the Commission's perspective.

I note that California regulations allow up to half of so-called battery electric vehicles (BEVs) to be "range extended" (BEVx) vehicles with a fuel other than electricity, so long as the range on the other fuel is no more than the all-electric range. For the midcontinent region I personally would not recommend restricting the range extension capability of the "BEVx" category of vehicles, as the California regulations do. My unsolicited advice to Illinois is that California regulations should not be adopted here unless range extension systems for BEVx battery electric vehicles be allowed to be greater than all-electric range. From the point of view of the Commission, this could be regarded as a strategy to reduce the need for daytime direct current fast charging, which would contribute to a lesser addition to peak demand by future battery electric vehicles (BEVs).

My enclosed comments are consistent with this position. For utilities I support emphasis on residential charging first, then public charging other than intercity fast charging. In the present vernacular, I recommend that distribution utilities support residential, workplace and community public charging (in that order) and not intercity corridor fast charging.

Thank you for the opportunity to comment.

Best regards;

Danilo J. Santini

Danilo J. Santini, Ph.D.

Response to the Illinois Commerce Commission Notice of Inquiry (NOI) Regarding Electric Vehicles

Danilo J. Santini
October 2018

Introduction and Justification for Support of Low Power Residential Charging

Suggested utility commissions goals:

First: Any additional plug-in electric vehicle customer will contribute to a net increase in the overall load factor of the existing generation, transmission and distribution system.

Second: Plug-in electric demand should conceptually be divided into base load, intermediate load and peak load. Plug in vehicle demand that maintains existing base-load generation capacity while expanding use of existing intermediate load generation is most desirable. Any increase in use of existing peak load generators or need for added amounts of peak load generation is to be avoided.

Considering costs of operation and specific attributes of different generation technologies, this means that one goal should be to increase the use of natural gas-fired combined cycle and wind generation. A second goal is to maintain use of base load generation capacity for coal and nuclear plants to retain the resilience of the system and to prevent costly base load unit shutdowns and restarts. Reduction of use of natural gas-fired combustion turbines, while maintaining their availability, is desirable — until and unless some plug-in vehicles can be linked to the grid to provide alternative short-term energy generation services.

Implications:

In practice, this means that each new plug-in vehicle customer should primarily cause a very high share of its electricity demand increases to occur overnight. The increase in daytime electricity consumption should be a small share, preferably in the morning and early afternoon. There should be very little or no increase in demand for power (kW) during peak periods — charging should be minimal in late afternoon in the summer and early evening during the rest of the year. Any customer that can logically be expected to add this balance of electricity demand to the grid should enjoy a lower cost per kWh of electricity purchases than average existing customers, even if the rate reduction is small.

Among new plug-in customers that meet these load pattern requirements, those who will commit to peak charging at 1 kW or less should not have to pay demand charges to support construction of new capacity. This can be accomplished in one of two ways.

(1) use an existing circuit capable of charging overnight for 12 consecutive hours at 1 kW (120 V, 8 amps).

(2) install a new dedicated circuit and electric vehicle supply equipment (EVSE) that will allow charging at 1.4 kW or above, along with a separate meter allowing hourly measurement of the actual charging activity, with either curtailment of charging at peak or deterrence via a very high penalty rate during on-peak periods. The penalty rate could be based on $/kWh or $/kW.

Logically, option 2 is much more expensive to a utility to implement than option 1. Option 1 provides the most existing technological opportunity. Under option 1 nearly all locations already having plugs near parking spots can charge plug-in electric vehicles. At residences, the quantity of overnight charging that could be provided can, on average, provide for most of each day's driving. Since no more electricity than needed for a day is provided, the pattern of charging for intensively used plug-in vehicles would be nearly every night. For leading selling plug-in hybrids in 2018, the range of kWh needed for a complete refill is from 6.2 to 16.4 kWh. If a residence could provide up to 11 kWh per night, among these vehicles, it could provide from 14 to 35 miles per day of electric driving. All electric vehicles are more efficient than plug-in hybrids. For the leading models from Tesla and the Chevrolet Bolt, the daily miles provided would be from 27 to 42 miles.

Option 2 is presently the recommended or only technologically possible strategy adopted by most plug-in vehicle manufacturers. These manufacturers and most policy makers (NASEO & Cadmus, 2018; Great Plains Institute, 2018) are asking for subsidies of option 2 and providing (or requesting) no subsidy or support for option 1. In fact, option 1 is not discussed and is not under consideration in consensus policy. In academic terms, neglecting option 1 promotes "technology lock-out", which is inherently limiting to deployment of new and used plug-in electric vehicles. Note that the majority of vehicles are used vehicles owned by middle to lower-middle income households whose residences will, on average, have less electrical power capabilities (a few kW) than residences of upper middle and upper income households. Utilities serve all customers, not just customers with new vehicles.

Findings from pilot programs show that the average cost of installation of EVSE for (1) residential, (2) workplace, (3) local public charging, and (4) intercity fast charging increases monotonically from 1-4. This cost increase is caused by a monotonic decrease in vehicle dwell time at the location. It is legitimate to presume that the customer will desire a significant number of miles of service from each charge event, regardless of time spent at the location. Accordingly, the kW capability demanded rises from category 1 to 4. This means that installation costs also increase. Another major issue is that the probability of charging on-peak increases from Category 1-4, so not only do capital costs of installation rise, average electric generation costs to provide the service also increase. Category 4 is most problematic. The policy maker's term for this type of charging is "corridor fast charging". From an engineers' perspective, it is called direct current fast charging (DCFC) providing 100 kW or more of charging capacity. This type of charging is most costly and least universally applicable to any plug-in vehicle. First, it applies only to all-electric vehicles. Second, there are three different technologies competing to be the leading technology, so an installation with a single specific technology supports only a fraction of all-electric vehicles.

Developing a charging system designed to first capture existing wind generation with existing electrical outlets, then developing new capacity for future solar.

Wind. A relatively unique characteristic of the "midcontinent" is now well understood (Great Plains Institute). Although coastal wind generation tends to be greatest during the day, within the midcontinental areas of the U.S. wind generation peaks overnight, causing "excess wind generation". There is an existing mis-match of wind supply and electric demand overnight. In detail, wind generation tends to peak in the early morning, before other electrical demand increases. Accordingly, there is a possibility of increasing the amount of wind generation captured in the early morning if utilities and automakers can work together to support overnight charging generally, and within the overnight charging period support a bias toward early morning charging.

Studies of existing "time of use" rates that were not developed for plug-in electric vehicles shows that these rates encourage pulses of electrical demand immediately after the time at which rates drop. In the "EV Project" experiments in San Diego showed that plug-in electric vehicles using the full charging capability (maximum kW) of the vehicles led to a pulse of demand (see Idaho National Laboratory, Fig. 10). Although evaluators did not recognize it, this confirmed prior analysis by Hadley and Tsvetkova of Oak Ridge National Laboratory (2008). Their analysis predicted such pulses should plug-in electric vehicles be charged at 6 kW instead of 1.4 kW. Their analysis predicted that these pulses of demand would cause greater use of inefficient natural gas combustion turbines (peakers).

Although effects on wind generation were not considered, multiple studies examined the consequences of different charging strategies for load shifts on the grid and distribution system. These studies recommended a strategy of charging where the owner would direct the vehicle to complete overnight charging just before the day's departure. The conclusion of analysts conducting these studies was that the problem of sharp pulses in system demand from a fleet of plug-in vehicles would be eliminated via the property known as "diversity". By completing their charging in the morning at a diverse number of times, plug-in vehicle owners would cause both the start and end of charging to ramp smoothly upward at the beginning and downward at the end. This would prevent sharp ramp rates that tend to cause relatively inefficient natural gas fired combustion turbines to be used. The smooth ramps would allow very efficient and clean natural gas combined cycle power plants to be used instead, which in turn would allow plug-in electric vehicles to use the lowest carbon fossil fuel generators in the existing grid mix.

While this advantage of early morning charging was recognized, another related advantage was not. Since the average daily diurnal wind generation pattern peaks in the early morning, this charging strategy also has the benefit that it would "catch the wind" that is currently wasted in the midcontinent.

A concern that has recently been expressed by the U.S. Department of Energy (2017) is the policy strategy of using wind generation to force old base load generation capacity to be shut down before the end of its useful life. Rules of dispatch used by regional system operators under deregulation is that the cheapest source of electricity to operate be called on first, and more expensive plants be shut down. Under these rules, a high amount of wind generation would require that coal and nuclear power plants be shut down. A requirement for base load plants to operate intermittently is essentially a "death sentence" since they were not designed originally with the expectation that they would be operated in that fashion. They become very expensive to operate if run intermittently.

If plug-in vehicles were to charge at the lowest points of system demand, they could be the "white knight" that keeps existing base load operators generating while still allowing wind generators to sell electricity. The most critical time of year with respect to wind is in the spring when wind supplies are highest and other electrical demand (heating and air conditioning) is lowest. Within the day, the lowest demand is at about 12 am to 2 am. If there is no other demand for wind generation at this time, under existing rules of dispatch, base load power plants would be asked to shut down. This potential problem can occur on any day, particularly on days with more wind. Thus, to reduce conflicts between wind generation and base load generation, consistent plug-in vehicle charging every day from approximately 12 am to 2 am is desirable.

This situation provides a potential motivation to control plug-in electric vehicle charging so that it happens between 12 am and 2 am. There are two kinds of control that could occur — passive and active. Under passive control, for those plug-in vehicle owners that have only an 8 ampere 1 kW charging circuit, those who want 11 kWh or more in their battery pack before the day's departure will need to charge for more than 11 hours and will likely be charging from 12 am to 2 am. Not all plug-in vehicle owners will need that much, but a significant fraction will. A second supplemental strategy is active control which would use higher power circuits in association with all-electric vehicles. In this case, the battery packs could have controlled variable charging during the week, with a higher rate of charging on days when wind supplies were highest. The former strategy is readily implementable with today's technology, while the second strategy requires technical and policy development and relatively costly EVSE capable of high kW operation with rapid kW variability achieved with active control.

Because of experience with electric vehicle experiments in the 1990s, it was learned that universal charging connector technology (cable to vehicle) and supporting standards were desirable. Two charging system specifications were developed, using a standard connecter design. These two are termed "level 1" (L1) and "level 2" (L2). L1 can provide from 1 to 2 kW of power. Level 2 can provide from 3 to 19 kW of power. A single connector and coupler specification, the SAE J1772 standard design, can serve either level, but maximum allowable voltages, amperes and kilowatts (kW) of circuit wiring to the electric vehicle supply equipment (EVSE) and the cable from the EVSE to connector can and do vary. Any of today's plug-in vehicles can technically use a level 2 EVSE with "off the shelf" products. Nearly all are also capable of using a level 1 EVSE, but those that are not presently designed for the owner to charge at 8 amps discourage using a standard wall socket due to fire risk. Often explicitly and sometimes implicitly, these manufacturers have chosen to promote only level 2 charging. Utilities are in the process of deciding whether to influence customers to choose L2 or L1, or to conditionally promote both. Within the range of kW capabilities that these connectors provide, utilities are also evaluating how much kW capability of EVSE should be promoted and/or discouraged. Most past research presumed that the lowest end power of L1 would provide 1.4 kW. However, after field experience with 1.4 kW, General Motors decided to reduce its default power setting for charging its Volt and Bolt models to 1.0 kW, by reducing default L1 charging at standard wall sockets to 8 amperes (amps) instead of the rated 12 amps. Owners manuals of other manufacturers that have not chosen to make this change emphasize that charging their plug-in vehicle at an existing standard circuit may not be desirable due to fire risk. Installation of higher power L2 circuits is implied to be desirable. Another recommendation (but not requirement) of standards designers is that plug-in vehicles use a "dedicated" circuit — a circuit that cannot be used by any electrical device other than the plug-in vehicle. Many candidate customers for a plug-in vehicle may have an existing standard socket and circuit that could serve the vehicle but could also serve lights or electrical tools as well. Obviously, replacing that existing circuit to allow use of a plug-in vehicle would cost money.

Unfortunately, the trend emphasizing that existing standard wall sockets and supporting wiring are not desirable is therefore unfavorable to sales of plug-in vehicles. Potential owners of plug-in vehicles that have an existing plug adequate to charge at 8 amps but would require significant costs to add a higher amperage dedicated circuit are less likely to become utility customers. This, in turn is not favorable to utilities because (1) policy makers are encouraging utilities to subsidize costs of installation of EVSE and/or upgraded circuits, and (2) a 1 kW limit essentially assures overnight charging with very limited (if any) peak period charging. Thus, because of the charging pattern advantages induced by limiting charging to 8 amps and 1 kW, it is recommended here that utilities put pressure on all plug-in vehicle manufacturers to design in a "default" 8 ampere charging rate with the on-board charger provided at the point of sale of the vehicle. Another default setting that should be encouraged would be for every plug-in vehicle to include a simple instruction (and capability) to select the time of charging to end in the morning. Once this capability is built into all vehicles, then dealers should set the default charging completion time within a morning window from 7 to 9 am, as preferred by the purchaser.

To summarize, this review implies that a 1 kW early morning charging strategy is desirable because it

(1) is off-peak
(2) takes advantage of diversity to assure slow charging ramp rates
(3) depends on safe use of the most widely available existing wall sockets and circuits
(4) will expand use of very efficient combined cycle power plants and wind generation
(5) will contribute to wind demand during times most threatening to base load generators

The best plug-in vehicle type to support this charging strategy is the plug-in hybrid.

Wind and Solar. In this section development of a long-term charging strategy to "catch the wind and soak up the sun" is discussed. Creating the opportunity to do both requires developing a total charging capability beyond the daily needs of drivers of plug-in vehicles. Doing so gives grid operators and vehicle owners the ability to selectively charge more on windy nights and/or sunny days and less on other days. The long-term system envisioned takes advantage of active control of plug-in vehicles. Significant amounts of L2 charging are added to serve both night and day charging of a portion of the future plug-in vehicle fleet. In this strategy all-electric vehicles would be favored due to the high power and energy of their large battery packs.

The problem for the grid operator that arises from wind and solar generation is intermittency. One way of dealing with this is to provide electrical storage (often, but not always batteries) capabilities at wind or solar farms. The problem with this is that during multiple day periods that the wind does not blow, and/or the sun does not shine, the storage facility cannot provide any transportation services. Having a battery pack in a vehicle that connects to the grid allows that storage system to provide transportation services from fossil or nuclear generation in addition to wind and solar, assuring continuous availability of electricity for transportation.

Auto manufacturers are promoting high kW charging along with the idea that the owner does not have to plug in very often. From the grid generation management perspective, this is bad precedent and undesirable policy. For controlled charging and discharging of plug-in vehicles to assist the grid the vehicles must always be plugged in. To the extent that actual movement of vehicles only takes place about 1.5 hours per day, and not all vehicles are on the road at the same time, this is, in principle, not a problem. However, the reality is that the vehicles end up parked at different locations. Thus, grid connections at multiple locations are necessary for plug in vehicles to provide reliable management of wind and solar intermittency. Vehicles used for work represent the best opportunity to provide relatively continuous night and day linkage to the grid at least total cost. Since peak solar power is on average provided in the early afternoon, the workplace is a good place to soak up the sun when its energy supply is at a maximum (Great Plains Institute, 2018).

In California, the success of centralized solar connected to the grid has been so great that base load generation can be asked to shut down during low periods of daytime demand. Due to its very small amount of solar capacity to date, the midcontinent is very far from the time that this will be a problem. However, solar *is* being installed, so the problem may emerge at some time in the future. Thus, it would be prudent to advance plan for workplace charging to enable solar energy capture.

Although some storage at wind and solar farms will likely always be technically desirable due to minute-to-minute and hour-to-hour intermittency, control of high power charging (demand management) has the potential to help system operators deal with the day-to-day intermittency of renewables generation as well as the average diurnal patterns of renewables. Being able to absorb high wind or solar generation on a given day and a given segment of the day can make the most use of these renewables. Having an ability to provide nearly all the day's charging needs at work as well as at the residence would allow a given vehicle to shift the time of charging to serve grid needs. Since many vehicles used for work remain there for 6 or more hours, it would still be possible to promote L1 charging at 2 kW at most workplace parking spots and thereby allow some night to day and/or day to day shifting. Until careful study is completed, utilities should err on the side of promoting L1 charging at work rather than more expensive L2. However, for public charging elsewhere, L2 charging is desirable, due to the short vehicle dwell times at such locations. Some "community fast charging" at other public locations (< 100 kW) may also be desirable.

Until and unless solar generating capacity in the midcontinent exceeds wind generating capacity, daytime workplace charging should remain secondary to residential overnight charging. It is desirable to price workplace charging at a higher rate than residential charging both because it requires costlier EVSE and because it is not off-peak. By doing so consumers will have an incentive to obtain most charging at the residence during off-peak periods. Alternatively and/or additionally, workplaces can restrict total kWh available to each plug-in vehicle to an amount consistent with supporting work commuting, but not other driving.

Suggestions on Appropriate Utility and Grid Management Strategy

Manufacturers of plug-in vehicles use engineers experienced with the "gasoline vehicle model". The thinking of these engineers is that fast refueling like a gasoline vehicle is necessary for plug-in vehicle success. Charts on the topic often point out how far electric charging must advance before it can match gasoline, generally observing that electric vehicle charging is very far from where it needs to be due to its low power delivery capabilities.

Most, but not all, plug-in electric vehicles come with a recommendation to the owner to install level 2 charging and supporting charge circuits rather than level 1. As discussed, this is not desirable for utilities. Although policy makers are requesting subsidy of level 2 charging because the automobile industry and electric vehicle enthusiasts believe it is necessary, this is not desirable from the utilities' perspective. Overall cost effectiveness must be proven under present utility regulation strategies. Further, allocation of costs to those customers that impose the costs on the utility and allocation of benefits to customers who better utilize the existing capacity of the utility are both desirable. Low power charging is more cost effective than high power charging. Overnight residential charging improves the utility load factor, while daytime charging is likely to worsen it unless carefully managed. Standard regulation theory says that imposition of requirements for added peak capacity should be assigned costs appropriate to that added capacity, rather than subsidy for the capacity. Inconsistent with these realities, many advocates of plug-in vehicles are promoting significant subsidy of daytime charging with little or no support for overnight charging (NASEO and Cadmus, 2018).

The manuals of plug-in electric vehicle manufacturers are now consistently advising owners to have an electrician check their charging circuit to be sure that the owner does not mistakenly attempt to charge at an amperage that could cause a fire. Midcontinent policy makers are not encouraging utilities to help either with L1 charging or with electrician expenses (Great Plains Institute, 2018). National policy evaluators are encouraging subsidy for installation of new L2 EVSE (NASEO and Cadmus, 2018), but not L1. Thus, present policy recommendations are consistent with option 2, which is a "technology lock-out" policy that will limit sales and resales of plug-in electric vehicles. The present policy recommendations regard a subsidy of $500 to be a weak policy, and $1000 or more to be a strong policy (NASEO and Cadmus, 2018).

Quality assurance – co-funding electrician's inspection of charging circuits. The recommendation here is that a strong policy is one that provides assurance to the maximum number of customers that they will be able to effectively use a plug-in electric vehicle to meet their driving needs. A strong utility policy would co-fund electrician inspections of every charging circuit that utility customers wish to consider for primary use for charging an intended plug-in vehicle purchase, along with an estimate of cost of upgrading any circuits that could not support 8 ampere 1 kW charging. Co-funding is desirable to prevent customer abuse. Although I am not aware of costs of electrician inspection and cost estimation, my assumption is that subsidies of as much as $500 should not be considered. Utilities should provide a subsidy substantially less than $500 for electrician inspections, subject to the provision that the electrician and/or owner provide a record of the inspection and (when applicable) the cost upgrade estimates. Allow the owner to request a rough upgrade estimate to whatever type and kW of EVSE that the consumer is interested in, with a cost share subsidy so long as the record of the estimate is provided to the utility. Such a program should enable utilities to gain an early indication of degree and nature (i.e. desired EVSE kW) of customer interest and charging capability.

Education about reasons for preferred charging. Early enthusiasts regarding plug-in electric vehicles are encouraging subsidies of level 2 charging and excluding level 1 charging. The Chevrolet Volt and Bolt are both designed for L1 default charging levels of 8 amps (1 kW). This default charging level is highly desirable for utilities. The reasons for this should be explained to customers and policy makers unfamiliar with utility cost management required by regulators. Warning of risk of fire if charging a circuit at too high an amperage is now prominent in some plug-in vehicle users manuals. Customers are encouraged to know the capability of the circuit they are using. Utilities should tell customers that they support 8 ampere 1 kW residential charging during overnight hours for multiple reasons, including:

(1) fire safety
(2) capture of wind generation
(3) increased use of the most efficient and cleanest fossil generators when they are used
(4) ability of the existing grid and distribution systems to safely and securely provide this level of service
(5) probable gains for grid resilience compared to an absence of plug-in vehicles on the grid

Consumers should be informed that afternoon charging on the hottest days is most risky to the grid and their electrical system, so the utility would appreciate the customer (even those charging at 1 kW) avoiding charging in the daytime on hot days.

Ideally, a rate reduction carrot — even if small — would be offered to customers, based on these desirable properties.

Four Examples and Interpretation

Minnesota's Great River Energy "Revolt" Electric Vehicle Charging - Dakota Electric Co-op program. This experimental program (http://www.energywisemn.com/revolt/) has several desirable properties. Its teaser for environmentally oriented plug-in vehicle owners is a promise to purchase wind energy credits if an all-electric vehicle or plug-in hybrid is purchased and recorded with the participating electric co-op. The form does not say "new" vehicle, so presumably used vehicles are eligible. This is highly desirable. (example - http://www.energywisemn.com/wp-content/themes/wiseenergymn/revolt/pdf/20180208/revolt_form_connexus.pdf). 5000 kWh of wind credits will be purchased annually for either the lease period or up to ten years of vehicle life. A questionnaire on consumer intent is included along with a question asking if more information about reduced charging rate programs is desired.

Two different rates are available https://www.dakotaelectric.com/wp-content/uploads/2016/09/EV_Programs.pdf. Pricing is based on $/kWh. The least cost "off peak storage" rate requires that charging only occur from 11 pm to 7 am. No charging is allowed at any other time in the day. In return for the guarantee of no peak charging and early morning charging, the rate is 4.4 cents per kWh. The other rate option (time of use) allows charging at any time of day. Overnight rates from 9 pm to 8 am on weekdays are 6.74 cents per kWh, while charging at this cost is allowed anytime on the weekend. Daytime off-peak charging from 8 am to 4 pm costs 13.08 (summer months) to 11.68 cents per kWh, while on-peak charging from 4 pm to 9 pm costs 41.44 cents/kWh. To obtain either of the rates the consumer must pay an unspecified amount for a submeter.

Austin Energy. Austin Energy is a public utility serving Austin Texas and some suburbs. In the Argonne review of causes of success of plug-in vehicle registrations that I collaborated on, Austin Energy stood out as far more successful in its region than elsewhere. Like Dakota Electric, Austin Energy supports installation of submeters to monitor hourly charging and included a significant penalty for afternoon on-peak charging (https://austinenergy.com/ae/green-power/plug-in-austin/home-charging/ev-home-rebate). Unlike Dakota Energy, a demand charge was used instead of a fee per kWh of charging. Level 2 charging is actively promoted and subsidized, along with the assumption that most plug-in vehicle owners will desire level 2 charging because of its speed. Original subsidies from a few years ago have been reduced from a maximum 50% cost share of $1500 to a 2018 maximum value of $1100 for a wi-fi connected EVSE, and $900 for an EVSE without wi-fi connectivity. Austin Energy includes a flat demand charge of $30/month for EVSE with 10 kW or less, and $50/month for more than 10 kW. Thus, the principle that greater EVSE kW capacity demand should cost more is followed (https://austinenergy.com/ae/green-power/plug-in-austin/home-charging/ev360). With a demand charge of $30/month, if a vehicle uses 10 kWh per day for 30 days the $/kWh cost would be $0.10 per kWh, so the effective rates at Austin Energy are higher than the off-peak rates at Dakota Electric. Off peak charging from 7 pm the first day through the following day until 2 pm has a per kWh cost of zero, while on-peak charging from 2 pm in the afternoon to 7 pm in the early evening costs 40 cents per kWh.

Free public charging is included, so owners of plug-in hybrids with significantly less than 10 kWh packs would have to charge twice a day to enjoy an effective rate as low as offered by Dakota Electric. Note that the electric meter is only necessary to measure (and deter) on-peak charging. If customers could only charge at a maximum of 1 kW, this meter could reasonably be eliminated.

In 2018 the program has been limited to 100 customers. For long-term success, utilities must find cost effective programs that they can support for any customer. The 2018 limits on the Austin Energy program and the reductions in subsidy amounts from initial values suggests that Austin Energy has not yet found an affordable "all-customer" strategy.

Consolidated Edison & Fleet Karma Smart Charge New York. While most smart charging programs use smart meters at the residence, in the Consolidated Edison Smart Charge New York program the monitoring and metering of the time *and location* of charging is recorded by a recording device installed on the vehicle. If charging anywhere in the New York service area takes place between midnight and 8 am (very similar to the early morning off-peak time window used in the Dakota Electric Co-op Storage rate option) a rebate of 5 cents per kWh is provided to the vehicle owner at the end of the year. There is also a demand charge incentive (rather than penalty) of $20/month for not charging on the summer peak. This reward is earned if there is no charging between the hours of 2 pm to 6 pm on weekdays from June to September (https://forums.tesla.com/forum/forums/fleetcarmas-smartcharge-new-york-too-good-be-true).

Xcel Energy Minnesota. In 2018 Xcel Energy of Minnesota adopted a pilot program open to 100 participants. No subsidies of installation of equipment are provided. If a residential customer wishes to install an EVSE with more than 5 kW of power, the "Frequently Asked Questions" (FAQ) pdf instructed the customer to "Contact Xcel Energy" (https://www.xcelenergy.com/staticfiles/xe-responsive/Marketing/MN-EV-FAQ.pdf). To obtain an off-peak rate exclusive to the plug-in vehicle, a separate electrical meter (not a submeter) is required and a cost of $4.95 per month is added to the bill. The customer is responsible for all costs of installation (but not the meter itself). The reduced off-peak rate is available nearly all night, from 9 pm to 9 am. Savings of $8.60 per month are estimated if 300 kWh/month are consumed. This amounts to about 3 cents per kWh. At a 4% discount rate the estimated savings per year of $103.20 would be worth about $840 if they continued for ten years. Since Xcel Energy estimates the cost of installation of equipment needed to obtain the rate to vary from $500 to $1500, many customers capable of estimating net benefits would choose not to participate.

For comparison, savings for 300 kWh of monthly charging only during the off-peak period under the Consolidated Edison Program would be $260 per year ($180 for charging off-peak and $80 for not charging on peak). As a customer incentive, the Consolidated Edison Program is far more attractive than the Xcel program. In the case of Dakota Electric, the Off-Peak Storage Program savings could be about $104 for summer months and $175 for all other months, totaling about $280 per year. For a three year lease the value of these savings would be about $775. For a ten-year vehicle life the savings would be worth about $2270. Since Dakota Electric splits EVSE installation costs with its share up to $500, then for cases where overall EVSE costs can be kept below $1000, customer cost is below $500. Average residential EVSE installation costs in the EV Project were $1325 (Idaho National Laboratory, 2015). Many customers could be enticed by the net savings possible with the Dakota Electric Off-Peak Storage program. More customers should be enticed by the Consolidated Edison program.

Comments on examples. Clearly, if the costs of new smart meters to measure amounts and times of kWh of consumption by plug-in vehicles could be eliminated and the need for costly circuit upgrades reduced, the attractiveness of plug in vehicles — particularly used vehicles — could be significantly improved. Reminding customers that Level 1 charging allows avoiding costs of EVSE upgrades is one strategy that utilities could adopt. Xcel's FAQ highlights the suitability of level 1 charging capability without EVSE installation, observing that "Level 1 charging can add ... roughly 60 miles of recharge each night." Whether intentional or not, the strategy of Xcel could be interpreted as biased toward Level 1 charging without EVSE rather than supporting Level 2 with EVSE. Xcel's choice not to subsidize Level 2 charging, along with implied concern over EVSE with 5 kW or more, implies that Xcel's calculations imply that Level 2 charging at the residence does not deserve subsidy. The Dakota Electric co-op choice to only provide $500 of subsidy also implies that only a subset of Level 2 EVSE installation opportunities will be worthwhile, and the utility wishes to limit its costs.

Two of the three examples include rate structure options to reduce off-peak electrical costs by 5 cents per kWh or more if charging occurs from about midnight to normal morning departure from work. The 8 ampere 1 kW charging strategy promotes most charging during this period of time. Plug in vehicles with battery packs of 8 kWh or more would extend charging further into the late evening of the day before and would consistently have a portion of their charging occur in the overnight trough in demand. Choices by Dakota Electric, Xcel Energy and Austin Energy to provide longer off-peak time windows (11, 12 and 19 hours respectively) suggest that even if Level 1 charging were limited to 8 amps and 1 kW, the usual daily driving needs of nearly all households could be met electrically with everyday unconstrained overnight charging ending at the morning time of departure of the vehicle used for normal workplace commuting.

Two of the three examples include changes of monthly demand charges in combination with changes of $/kWh costs. The Smart Charge New York program includes a reduction in summer month fixed costs as a reward for desired charging behavior. Austin Energy uses an increase in monthly fixed cost, effectively promoting intensively used plug-in vehicles with larger battery packs.

Use demand charges and credits rather than $/kWh charges to defray local distribution savings and costs.

Regulatory practice separates demand charges, which are usually fixed charges per billing period, from consumption charges. Put another way, demand charges are fixed charges independent of kWh that are intended to defray costs of construction of capacity, while consumption charges ($/kWh) are intended to cover variable costs of operation. For renewables such as wind and solar nearly all costs are capacity costs. Variable costs are very low. Thus, policy intended to support renewables should focus on use of demand charges rather than operations charges such as $/kWh.

Demand charges (increases) provide an incentive for intensive use and a disincentive for adding peak capacity. I suggest that the cost of electricity for plug-in vehicles should send clear signals that utilities wish to have the lowest power circuits installed that will meet customer needs. If the added residential load from a PEV has a much lower percentage of kWh occurring on-peak than does the existing load for the house, the addition of the PEV should lead to a reduction in average monthly demand (or fixed) charges for that house. Further, as we have seen, EVSE kW capacity increases push up costs. Thus, as in the rough example by Austin Energy, the demand charge should increase as the kW of the EVSE increases.

I have argued that the probable load patterns of plug-in vehicles using 1 kW charging will be very favorable. These vehicles will be charged overnight when they are parked at the residence. Since plug-in vehicles are expensive and efficient, economics dictates that they will be used during the day, so they will seldom be at the house. About 15% of vehicles that are used on a given day return to the house before 6 pm on that same day. With a 1 kW charging limit, peak load for plug-in vehicle charging will be far more favorable than the existing house load. As an example, assume that a reduction of 5 cents per kWh is desired for 8 hours of early morning charging (or 8 kWh of plug-in hybrid battery pack capacity). If the vehicle is charged overnight 30 days per month, then a reduction of $12/month would provide the desired reward for those customers. Unfortunately, the direction of incentive when a reduction in fixed charge is offered is not desirable (plug-in vehicles with smaller battery packs get the same savings).

This strategy avoids the need for a meter to measure and deter peak period use and sends the right general signal to customers.

Utilities could consider also offering such an incentive for sockets capable of 1.4 kW. However, as the kW capability of the circuit and socket increase less charging will take place during the midnight hour, so lower overall spring and fall troughs in demand will occur, pressuring base load generators to shut down, potentially reducing grid resiliency.

If the utility decides that a credit of $12/month is a reward for charging at 1 kW, while charging at 2 kW is not to be incentivized, then the shift in cost per kW would be $12/kW. If $12 were charged for every kW of EVSE capacity over 1 kW, then 3 kW instead of 1 kW would cost a customer $24 per month, or $288 per year. The costs need not be this high. Recall that Austin Energy chose to charge $30/month for the level 2 charging capability that customers install. Recall also that Xcel Energy wanted the customer to contact them if the EVSE kW was 5 or more. Most residential EVSE to date have been between 3 and 4 kW, consistent with the maximum capabilities of most plug-in hybrids through about 2017. However, charging capabilities of plug-in hybrids are increasing to the 6-7 kW range.

My suggestion is that EVSE fixed costs per added kW above 1.0 should be at least $5 per month. This would make an 11 kW EVSE cost $50/month, which is what Austin Energy chose to charge for any EVSE with more than 10 kW of power.

If the charge is applied to fractions, and if the example of a $12/month subsidy for 8 ampere 1 kW charging is the starting point, then the subsidy for 1.4 kW L1 charging (12 amp, 120 V) would drop to $10/month and for 2.0 kW to $2/month.

Monitor changes in load from 1 kW charging and allocate resulting benefits to the entire system.

In principle, a subsidy for use of a 1 kW charging circuit should be split between the distribution company and electricity suppliers. Note that distribution utilities and clean efficient electricity generators realize a net gain in revenue. Although accurate allocation of fuel charges would in theory require a smart meter for hourly measurement, the costs would not justify the benefits. Nevertheless, fuel savings, carbon benefits and maintenance of system resiliency would result from this residential charging constraint. Utility commissions should see that these benefits are estimated and that average fuel charges are also appropriately reduced when residential grid customers charge at Level 1 power levels.

Since one intended and expected benefit of overnight plug-in vehicle charging is increased utilization of existing wind generation capacity, immediate promotions of the benefit of the linkage to environmentally oriented customers are desirable. Although the overnight charging load increase will not be entirely met by increases in wind generation, allowing and/or encouraging some of the revenue gains from new plug-in vehicles to be used to purchase renewable wind credits is a legitimate immediate strategy.

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